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An Experimental Investigation of Cutting Condition Influences on Hard Milling of AISI D2 Tool Steel

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ABSTRACT: The presented work aims to study the effects of cutting speed, feed rate and depth of cut on surface roughness R_a in hard milling of AISI D2 steel (58 ÷ 60 HRC) using carbide inserts. A factorial experimental design was used to evaluate the influence of input variables. The obtained results indicated that feed rate causes the most significant effect on surface roughness, whereas cutting speed and depth of cut have little influence. The interaction effects between cutting speed and depth of cut as well as between feed rate and depth of cut have the significant influences on surface roughness R_a. Moreover, the cutting speed of 92 ÷ 100 m/min, feed rate of 0.1 ÷ 0.11 mm/tooth, and cutting depth of 0.1 ÷ 0.12 mm should be recommended for reaching the smaller surface roughness R_a values, which play an important role for further studies on hard milling process.

KEYWORDS: Hard milling; cutting parameter; cutting speed; feed rate; depth of cut; surface roughness

1. INTRODUCTION

In metal cutting field, milling is the commonly used machining method for flat surfaces. This method uses cutting tools with multiple cutting edges, so it provides high machining productivity and plays an important role in production practice [1]. Especially in the mold industry, most of the workload is handled by the milling process [2]. Thanks to the rapid development of CNC machine tools, the milling process has now been automated and has brought remarkable effects in productivity, surface quality and machining cost reduction. On the other hand, increasing requirements on mold material properties are posing new challenges in milling technology.

Nowadays, materials with high strength, hot hardness, corrosion resistance, and good abrasion resistance are common requirements, including AISI D2 tool steel. However, these materials are classified as difficult-to-cut materials and the machining process requires high requirements in choosing cutting tools and cutting modes. Among cutting tool materials, coated carbide tools show the advantages of high hardness, high abrasion resistance, reasonable cost, especially good impact resistance [3], so this cutting tool material is widely used in milling technology. Hard milling is a development step of traditional milling process and has attracted much attention from researchers and manufacturers in the field of mold machining [2,4].

The direct cutting of heat-treated steels with high productivity has introduced a new technological solution that supports or replaces the grinding process [5]. Besides, hard milling provides high dimensional accuracy and good surface quality. However, the studies on hard milling of AISI D2 tool steel are still limited [6]. Therefore, the author conducted a study on the influence of cutting mode including cutting speed, feed rate and depth of cut during hard milling of AISI D2 tool steel (58÷60HRC) on surface roughness R_a. The main effects and interaction effects between input parameters are discussed in detail and reasonable sets of technological parameters are proposed from the results of this study.

2. METHODOLOGY

The cutting trails were implemented on MCV-410 milling machine under wet condition, Japan (Figure 1). AISI D2 tool steel (58÷60HRC) was used. The surface roughness measurement process was conducted three times after each cut and the average value was taken. The factorial experimental design with the help of Minitab 19 software was used to study the effects of cutting speed, feed rate, and depth of cut on surface roughness R_a. The input parameters with their value levels and response variable are given in Table 1.

Figure 1. Experimental set up

Table 1. Input variables and their levels

Input variables	Low level	High level	Output variable
Cutting speed (m/min)	70	100	Surface roughness R_a (µm)
Feed rate (mm/tooth)	0.1	0.2	
Depth of cut (mm)	0.1	0.2	

3. RESULTS AND DISCUSSION

The experimental trials were carried out by following the factorial experimental design. The results in the Pareto charts exhibit the influence of each parameter and the interactive effects of the input parameters on the output variable shown in Figures 2. In Figure 2, it can be seen that feed rate is the parameter that has the strongest impact on surface roughness R_a. The influences of cutting speed and depth of cut are little because they are located to the left of the reference line.

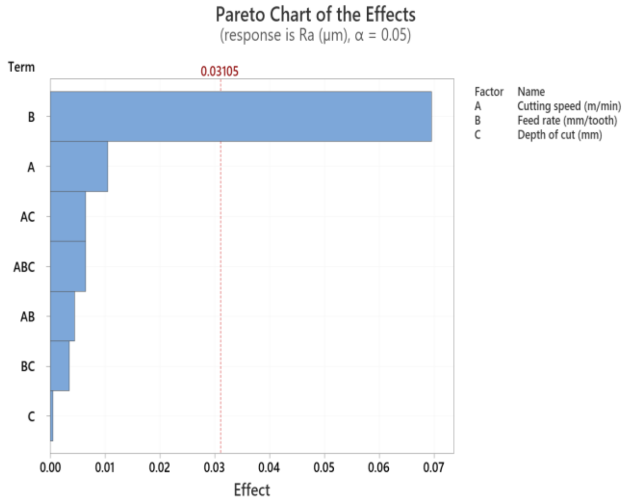

Figure 2. Pareto chart of the effects of input variables on surface roughness R_a

In Figure 3, it can be seen that cutting speed has the greatest influence on surface roughness R_a due to the increase of the area of the cross-section of the cutting layer. The increase of cutting speed contributed to reduce the surface roughness, which can be explained by the reduction of cutting forces and cutting heat [2]. The plot of interaction effects of input parameters was shown in Figure 4, and it can be seen that the interaction effects between cutting speed and depth of cut as well as between feed rate and depth of cut have the significant influences on surface roughness R_a.

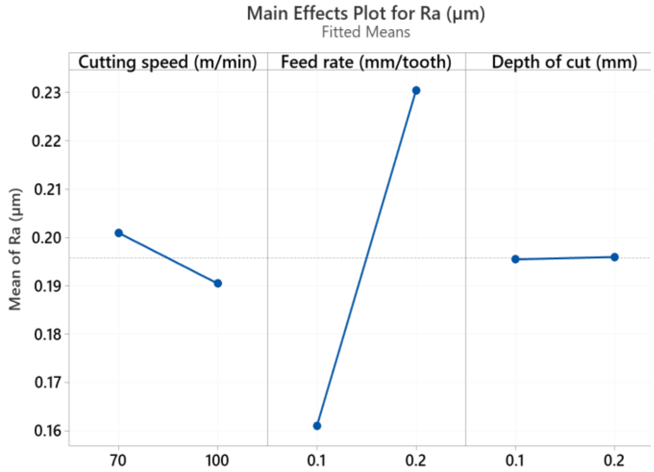

Figure 3. Main effects of input variables on surface roughness R_a

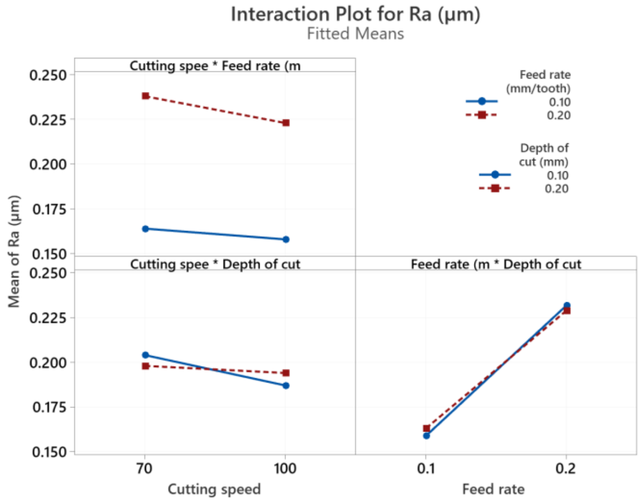

Figure 4. Interaction effects of input variables on surface roughness R_a

In Figure 5, the contour plot shows the effects of feed rate and cutting speed on surface roughness R_a. In order to achieve the smaller R_a values (R_a<0.16 µm), the feed rate of 0.1÷0.11 mm/tooth combined with the cutting speed of 90 ÷ 100 m/min should be used when the depth of cut is fixed at 0.15 mm. For the feed rate fixed at 0.15 mm/tooth, the cutting speed of 92÷100 m/min and depth of cut at 0.1 ÷ 0.17 mm would be recommended to achieve the smaller R_a values (R_a< 0.18 µm) (Figure 6). In Figure 7, when the cutting speed is fixed at 85 m/min, feed rate of 0.1 mm/tooth and cutting depth of 0.1÷0.12 mm should be used to achieve the smaller R_a values (R_a<0.16 µm).

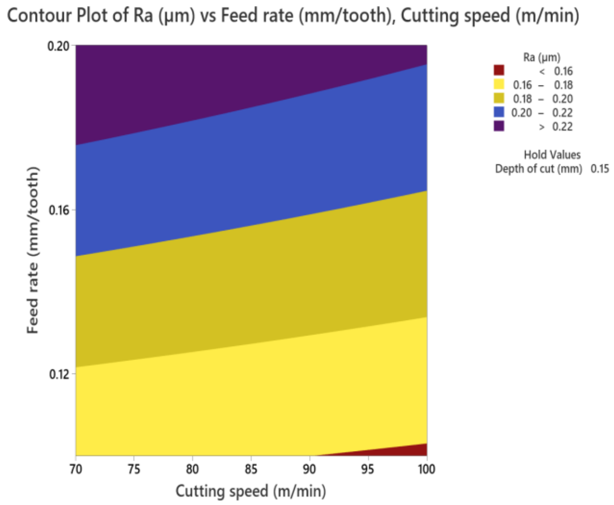

Figure 5. Contour plot of effects of feed rate and cutting speed on surface roughness

Figure 6. Contour plot of effects of depth of cut and cutting speed on surface roughness

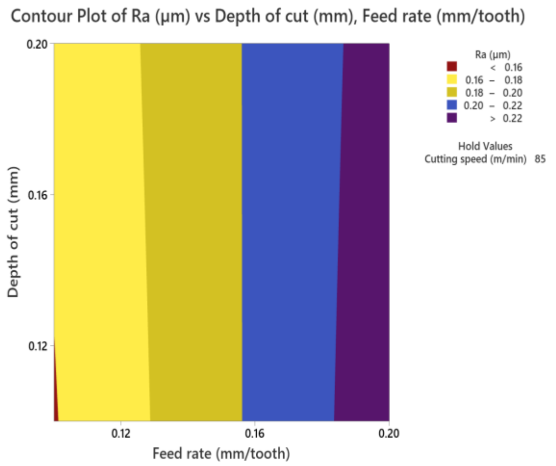

Figure 7. Contour plot of effects of depth of cut and feed rate on surface roughness

Accordingly, the reasonable ranges of cutting parameters are the cutting speed of 92÷100 m/min, feed rate of 0.1 ÷ 0.11 mm/tooth, and cutting depth of 0.1÷0.12 mm for reaching the smaller surface roughness R_a values.

4. CONCLUSION

In the work content, the effects of cutting parameters on surface roughness R_a in hard milling of AISI D2 steel (58 ÷ 60 HRC) using carbide inserts under wet condition were studied. A factorial experimental design was used to evaluate the influence of parameters including cutting speed, feed rate and cutting depth, thereby providing influence trends and interaction effects on surface roughness. Feed rate is still the parameter that has the greatest influence on surface roughness, but cutting speed and depth of cut have little impact. The interaction effects between cutting speed and depth of cut as well as between feed rate and depth of cut have the significant influences on surface roughness R_a. Furthermore, the cutting speed of 92 ÷ 100 m/min, feed rate of 0.1 ÷ 0.11 mm/tooth, and cutting depth of 0.1 ÷ 0.12 mm should be used for achieving the smaller surface roughness R_a values.

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